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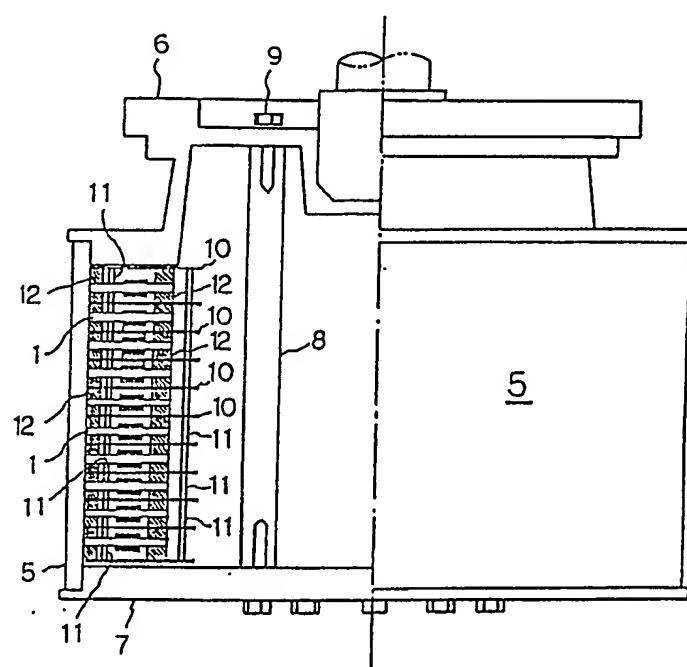
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(54) Ultrasonic transducers

(57) The present invention is directed to an ultrasonic device comprising a plurality of transducer elements 1 arranged in rows and columns and acoustic insulation material 12 maintained between two adjacent transducer elements. The ultrasonic device comprises (i) a plurality of circular rows of the transducer element 1 disposed on an imaginary circle, (ii) a plurality of circular plates 10 each supporting one of said rows and (iii) spacers 11 for spacing the two adjacent plates of said plurality of the plates at a predetermined space interval, thereby obtaining a cylindrical array. The stacked arrays are enclosed in a water-tight housing 5.

Other embodiments involve arcuate or linear rows instead of circular rows.

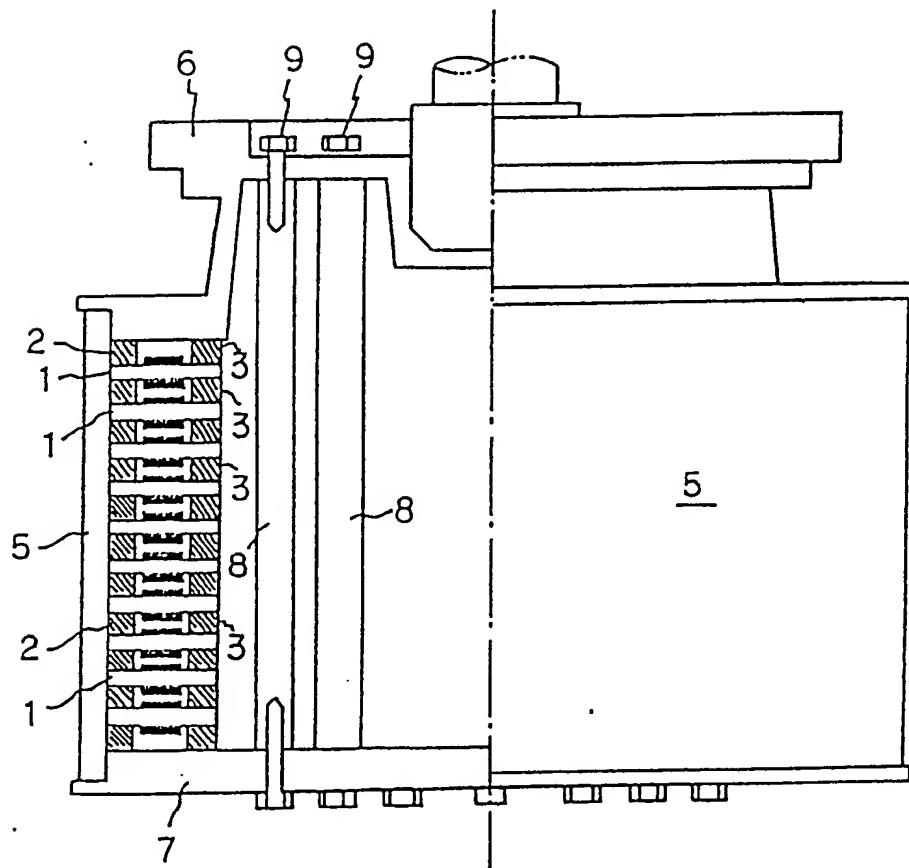
Fig. 4



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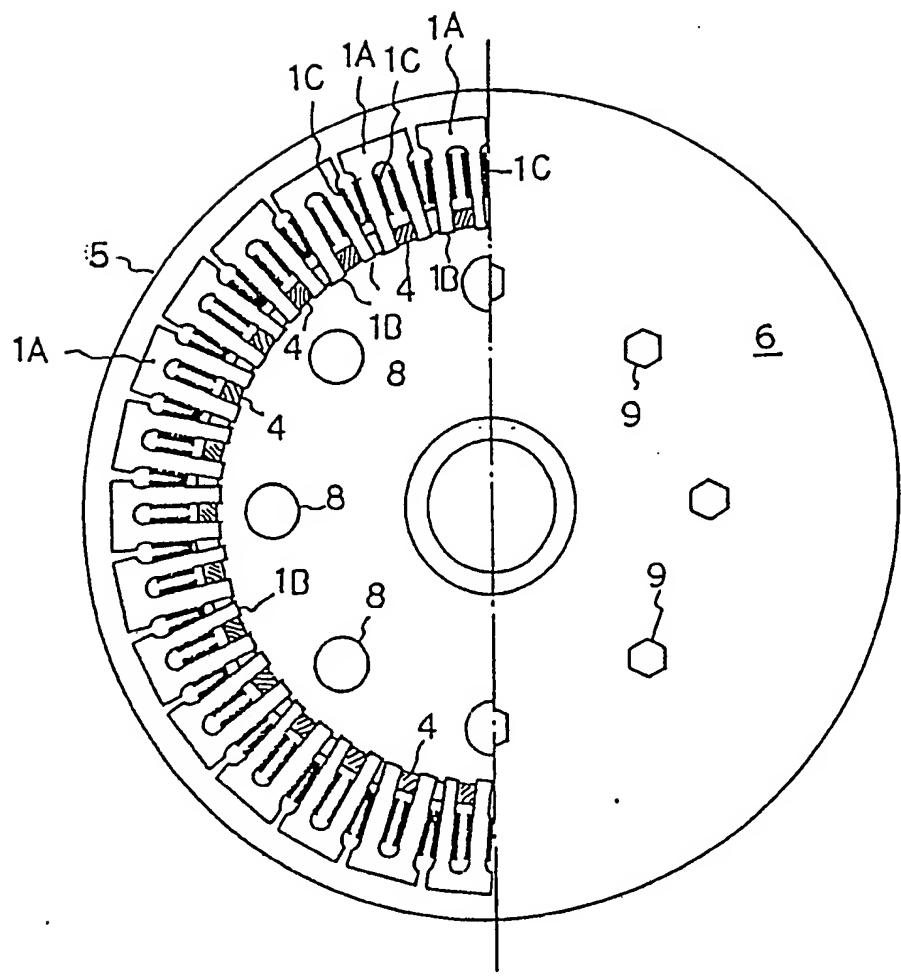
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Fig. 1



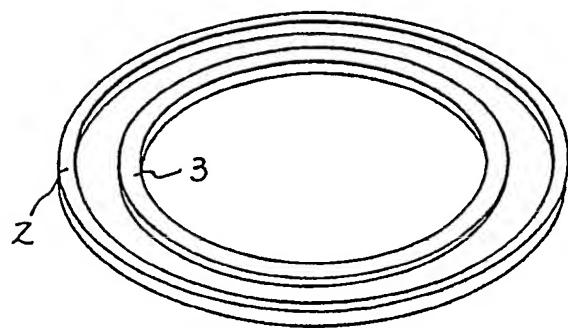
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Fig. 2



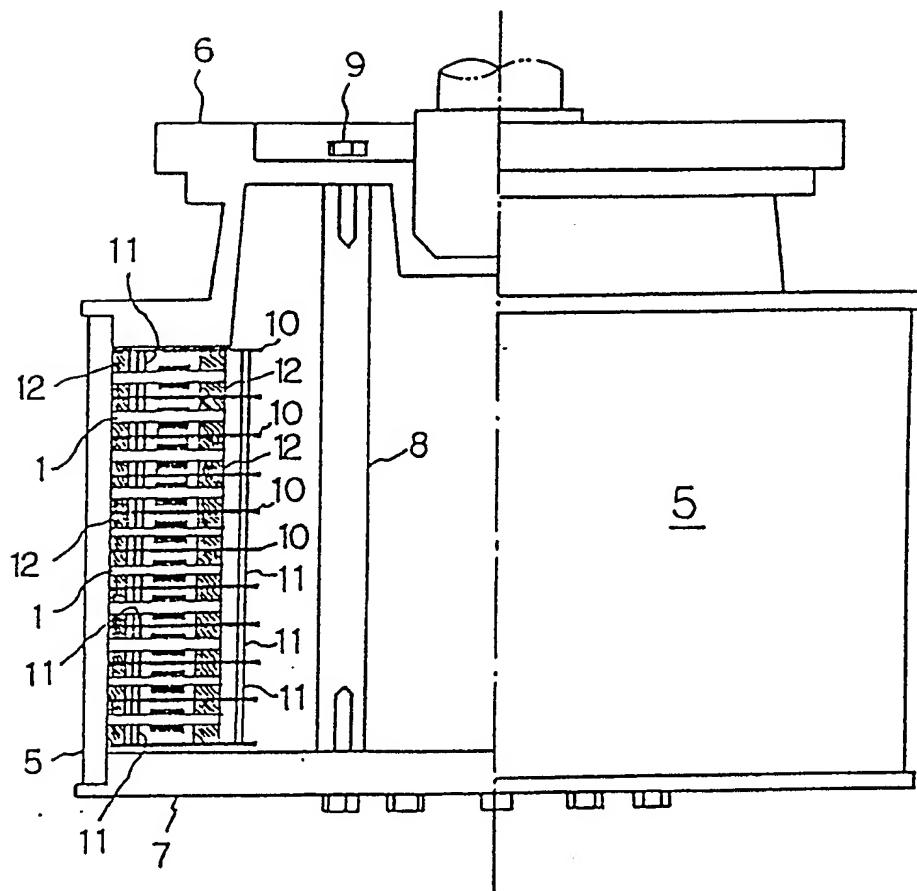
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Fig. 3



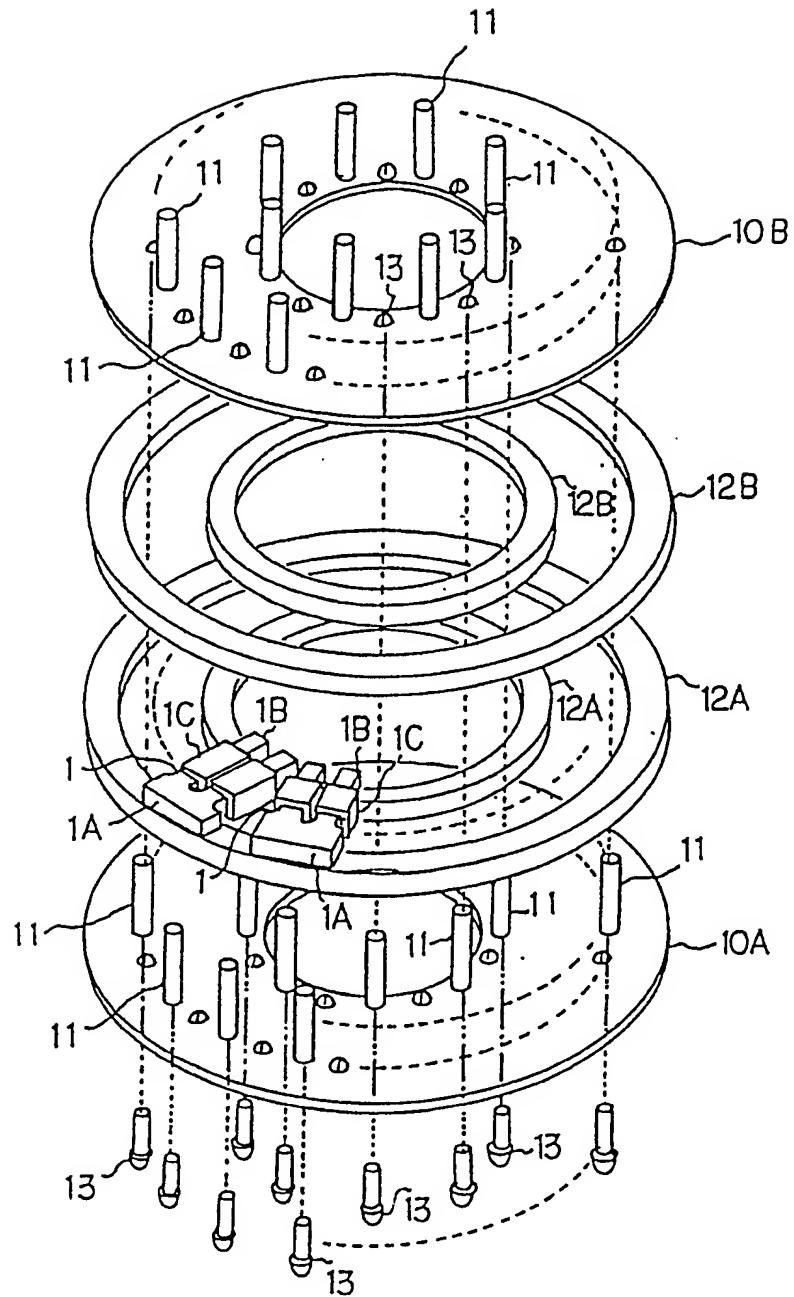
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Fig. 4



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Fig. 5



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Fig. 6

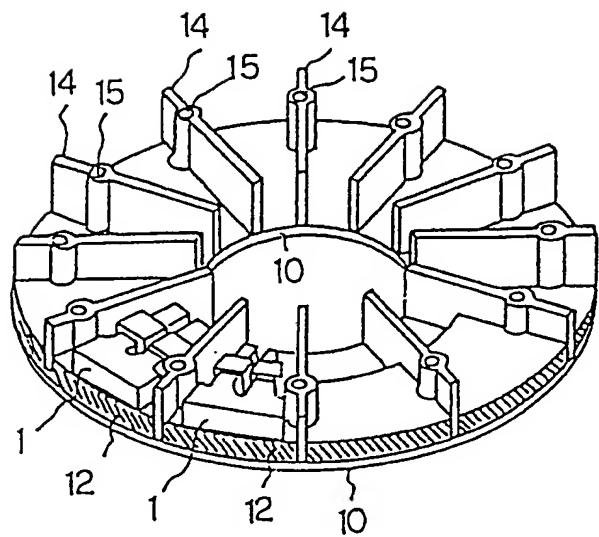
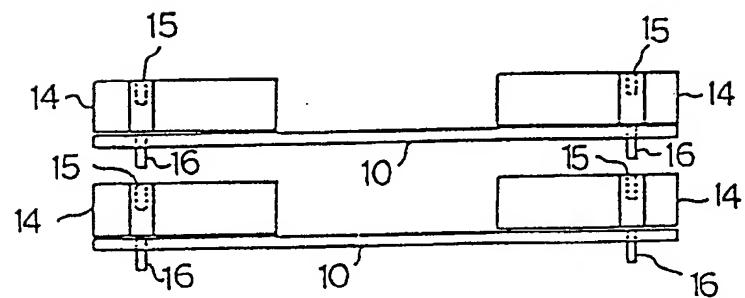


Fig. 7



SPECIFICATION**Transducer device****5 Background of the invention**

The present invention relates to an ultrasonic transducer device comprising a plurality of transducer elements arranged in rows and columns and acoustic insulation material maintained between two adjacent transducer elements for converting electrical energy into ultrasonic wave energy to be radiated into the water and vice versa. Particularly, the invention relates to the improved structure of the transducer device.

15 The transducer elements may be disposed on a plane in rows and columns at uniform or different space intervals in one of mutually perpendicular directions or in both directions thereof, thereby obtaining a planar array of the transducer elements.

20 The transducer elements may be disposed in rows and columns along the circumference of a cylinder at uniform or different space intervals, thereby obtaining a cylindrical array. As the transducer elements, magnetostrictive or electrostrictive ultrasonic trans-

25 ducers may be used.

An ultrasonic transducer device of this type has been proposed by the applicant and disclosed in a laid-open Japanese Patent Application No. 25080 of 1981. Referring to Figures 1, 2 and 3, the conventional transducer device will be explained. Numerals 1, 1... are magnetostrictive transducer elements of the x-type. Thirty of the transducer elements are disposed on an imaginary circle at angular uniform intervals, thereby forming a circular row of the transducer elements. There are ten such rows from the top to the bottom of the transducer assembly. The transducer elements of each row are acoustically insulated from the ones of rows adjacent thereto by transducer liners 2, 2... and 3, 3... made of acoustic insulation material such as cork or foam urethane. The outer transducer liner 2 and the inner transducer liner 3, each shaped in a ring form, are disposed concentrically on an imaginary plane, as illustrated in Figure 3. The x-type magnetostrictive transducer elements 1, 1... are circularly mounted on the transducer liners 2 and 3 at uniform angular intervals in radially extending relation. The transducer elements are disposed on the transducer liners 2 and 3 in a manner that the sound sensing part of each one of the transducer elements 1 is supported by the outer transducer liner 2 and the leg parts thereof are supported by the inner transducer liner 3, as shown in Figure 2. The sound sensing part 1A of each one of the transducer elements is stucked to the outer transducer liner 2, and the leg parts thereof are supported by the inner transducer liner 3 with their surfaces merely kept in contact with the surface of the transducer liner 3 so that their vibration energy can be derived by coils 1C in a form of electric signal. Each one of permanent magnets 4 is maintained between the legs of each one of the transducer elements 1 to provide a biasing magnetic field, and is fixed to the inner transducer liner 3. The front surface of the transducer elements arranged in thirty straight columns and ten circular rows with the

transducer liners 2, 3 being inserted between the adjacent rows of the transducer elements, are covered by sound passing material Rho-C rubber such as urethane rubber, which is molded. Ultrasonic waves are transmitted and received into and from the water through the molded cover 5. Thus, the outer transducer liners 2 are supported by the molded cover 5 cylindrically shaped. Each one of the transducer elements 1 is stucked to the outer transducer liners 2. The inner transducer liners 3 support the leg parts 1B of the transducer elements 1. Each one of the permanent magnets 4 maintained between the leg parts of the each transducer element 1 is stucked to the inner transducer liner 3. Hence, the inner transducer liners 3 are concentrically disposed with respect to the outer transducer liners 2. The transducer elements in rows and columns and the transducer liners maintained between the two adjacent rows of the transducer elements are arranged in a cylindrical form. The cylindrical transducer assembly is closed by an upper end head 6 and a lower end head 7 water-tightly by means of support shafts 8 and cap screws 9.

Thus, the conventional transducer device has been constructed in a manner that the transducer elements arranged in ten circular rows and the transducer liners 2, 3 maintained on and beneath each row of the transducer elements are pressed by the upper and lower end heads 6, 7 to be held. The transducer liners 2, 3 must be made of hard material so that the transducer liners are not deformed due to the pressure imposed by the end heads 6, 7. Cork or foam urethane have been employed as the hard material. These materials perform the acoustic shielding between the transducer elements of the two adjacent rows, since air is contained in small holes extensively formed therein. When pressing forces are given to the material, the small holes shrink by small amounts, thereby reducing the whole material in size by a small amount accordingly. In order to cope with this problem, the transducer liners 2 and 3 have been manufactured as a little larger than desired. A desired thickness of each one of the transducer liners has been obtained by the pressing force given thereto when the transducer device is assembled as illustrated in Figure 1, thereby shrinking the transducer liners.

However, it is impossible to manufacture the transducer liners 2, 3 in such a way that the height of each one of the transducer liners is exactly the same as that of the others. The thickness of the transducer liners manufactured varies from one to another. Further, the shrinking degree of the liners differs depending on the number and size of the small holes therein containing air even if the same pressing force is given thereto. Accordingly, when the transducer liners, 2, 3 and the transducer elements 1 stacked are pressed from the upper and lower directions to be held, the shrinking degree of the transducer liners 2, 3 differs from one to another, so that the space intervals between the vertical adjacent transducer elements differ from one to another by small amounts. Such unequal space intervals between the vertical adjacent transducer elements considerably affect the performance of the transduc-

er device. With the transducer device, the ultrasonic waves radiated from a plurality of the transducer elements or the echo signals caught thereby are combined together in phase. It is important to
 5 dispose the transducer elements at a predetermined interval between the two adjacent rows of the transducer elements. If the intervals between the vertical adjacent transducer elements are different from the predetermined one, a directional pattern
 10 can not be formed in a specific direction by combining in phase the ultrasonic waves transmitted from the transducer elements or the echo signals caught thereby, or transmission or reception sensitivities, i.e., side lobes in undesired directions increase, thus
 15 considerably deteriorating the performance of the transducer device.

Further, the pressing forces produced by the upper and lower end heads 6,7 directly act on the transducer elements 1, so that the increase of the pressing forces gives a load to the vibration operation of the transducer elements 1. Therefore, the pressing forces produced by the heads 6, 7 must be set so that the vibration operation of the transducer elements 1 is not affected.

25 The transducer assembly shown in Figure 1 is extremely weak against the force acting toward the molded cover 5 from the outside thereof. In other words, the transducer elements 1 and the transducer liners 2, 3 stacked are likely to be deformed or
 30 displaced, when forces from the outside act thereto through the molded cover 5. Accordingly, the whole transducer device shown in Figure 1 must be housed in a dome, thus making the size of the whole device larger. The transmission loss of the ultrasonic waves
 35 becomes greater, since they are transmitted or received through the dome.

Accordingly, an object of the invention is to provide a transducer device comprising a plurality of transducer elements arranged in row and columns, 40 which can be easily assembled.

Another object of this invention is to provide a transducer device in which a plurality of transducer elements are precisely disposed at predetermined space intervals, so that a directional radiation or 45 reception pattern is formed in a specific direction and the amplitude of side lobes is reduced.

One more object of this invention is to provide a transducer device which is strong enough to stand external forces acting thereto and hence can be 50 directly exposed to the water.

Summary of the invention

In order to achieve these and other objects of the invention, in accordance with one aspect of the
 55 present invention, a transducer device is provided which includes (i) a plurality of rows of transducer elements, with said each row comprising a plurality of transducer elements disposed on an imaginary line, (ii) a plurality of plates, with said each plate
 60 supporting one of said rows of the transducer elements, (iii) spacers for spacing the two adjacent plates at predetermined space intervals, (iv) acoustic insulation maintained between said two adjacent rows of the transducer elements (v) sound passing
 65 material covering the front surfaces of said transduc-

er elements, and (vi) enclosing means for water-tightly enclosing said transducer elements supported by said plurality of plates except the front surface of the device formed by said sound passing material.

Other objects and features of the present invention will be described in more detail herein with reference to the accompanying drawings.

75 Brief description of the drawings

Figure 1 is an elevation view of a conventional transducer device partly and longitudinally sectioned;

80 Figure 2 is a plan view of the conventional transducer device partly sectioned;

Figure 3 is a perspective view of the transducer liners used in the conventional transducer device;

85 Figure 4 is an elevation view of a transducer device in accordance with an embodiment of the present invention, partly and longitudinally sectioned;

Figure 5 is an explanatory diagram for explaining the main part of the transducer device shown in Figure 4;

90 Figure 6 is a perspective view of a part of a transducer device in accordance with another embodiment of the present invention; and

Figure 7 is a side view of the part sectioned of the transducer device shown in Figure 6.

95 Throughout the drawings, the same reference numerals are given to like components.

Detailed description of the preferred embodiments

Referring to Figure 4, circular plates 10 are made of non-magnetic material such as aluminum or copper. Spacers 11 made of hard non-magnetic material are shaped in a columnar form and have screw holes at their both ends. The spacing rods 11 are fixed at their both ends to the two adjacent

105 circular plates with cap screws, thereby obtaining ten stories, in each of which the transducer elements 1 are housed. The height of each of the story, i.e., the space interval between the adjacent circular plates 10 is determined by the length of the spacing rods

110 11. Transducer liners 12 are, for example, made of soft acoustic insulation material as sponge, and shaped in a ring form. The outer and inner transducer liners 12 are stucked to both sides of the circular plate 10. The transducer elements 1 are maintained between the transducer liners 12 fixed to the lower side of an upper circular plate 10 and the ones fixed to the upper side of a lower circular plate 10.

115 Referring to Figure 5, lower outer and inner transducer liners 12A are concentrically disposed and fixed to a lower circular plate 10A, while upper outer and inner transducer liners 12B are concentrically disposed and fixed to the lower side of an upper circular plate 10B. The transducer elements 1 are fixedly arranged on the transducer liners 12A at uniform angular intervals in radially extending relation. The sound sensing part 1A of each one of the transducer elements 1 and the leg parts 1B thereof are stucked to the outer and inner transducer liners 12A respectively. The height of the transducer liners

125 12A, 12B is determined in such a way that the
 130 12A, 12B is determined in such a way that the

exciting coils 1C do not touch the circular plates 10A, and 10B, when the transducer elements 1 are mounted on the transducer liners.

The circular plates 10A, 10B fixedly maintain the 5 transducer elements 1 through the transducer liners 12A, 12B, and are fixedly connected with each other by means of the spacing rods 11 and screw bolts 13. Thus, the space interval between the circular plates 10A and 10B is determined by the length of the 10 spacing rod 11. The length of the spacing rod 11 is determined in such a way that the space interval between the two vertical adjacent transducer elements becomes a desired one, when the circular plates 10 are stacked and the transducer elements 15 are housed in each resultant story as illustrated in Figure 4.

After eleven circular plates 10 are connected with the spacing rods 11 at uniform space intervals therebetween, they are pressed to be held by the 20 upper and lower heads 6, 7 from the upper and lower directions. The transmission and reception surfaces of the transducer elements 1 are covered by sound passing material such as urethane rubber.

As apparent from the foregoing, the transducer 25 elements of each row disposed on an imaginary circle are fixedly supported by the corresponding circular plate 10. The space interval between the adjacent circular plates is determined by the length of the spacing rods 11. Therefore, even when the 30 stacked body obtained by connecting the eleven circular plates 10 with the spacers 11 is pressed by the upper and lower end covers 6, 7, the resultant pressing forces do not act on the transducer elements directly.

35 The arranged transducer elements 1 are not affected by outer forces acting on the front surface of the molded cover 5, since the circular plates 10 connected with the connecting rods 11 are of sufficient mechanical strength to stand the forces. 40 Hence, the transducer device can be directly exposed to the water and is driven to radiate and receive ultrasonic waves directly, without housing the device in a dome as in conventional devices. This results in the decrease of the sound transmission 45 loss of the ultrasonic wave energy.

The distance between the adjacent rows of the transducer elements which are disposed on a horizontal imaginary circle is determined by the length of the spacing rods 11, and hence is not changed due 50 to the pressing forces imposed. Accordingly, the present invention is capable of providing a transducer device having a good directional radiation or reception characteristic, since the distance between the vertical adjacent transducer elements can be 55 easily set at a desired one.

The transducer liners 12 can be made of soft material such as sponge, as opposed to conventional transducer liners which are made of hard material as cork or foam urethane, since the transducer liner 60 12 merely supports the transducer elements of one row. Sponge contains more small holes containing air than cork or foam urethane. Thus, the sufficient acoustic shield is attained.

Further, the circular plate 10 made of non-magnetic material such as copper or aluminum

provides electrostatic and magnetic shields between the vertical adjacent transducer, thereby preventing electric interferences from occurring therebetween.

Referring to Figures 6 and 7, spacers 14 are shaped 70 in a rectangular form and are disposed on the circular plate 10 at uniform angular intervals and fixed thereto in radially extending relation. The spacers 14 have vertical reception holes 15, while the circular plate 10 has pins 16 at positions corresponding 75 to the reception holes 15. The pins 16 of each one of the circular plates 10 are inserted into the reception holes 15 of the spacers standing on one of the other circular plates 10, thus obtaining ten stories for housing the transducer elements. The 80 transducer liners appropriately cut are placed in partitioned sections as shown in Figure 6. An integrated circular plate 10, rectangular spacers 14 having holes 15 and pins 16 can also be manufactured.

85 Although the circular plate 10 is made of non-magnetic material such as aluminum or copper in the foregoing embodiments of the invention, it should be noted that the circular plate 10 may also be made of hard resin material such as plastics. It is 90 also possible to coat the surface of the resin material with a thin layer of copper or aluminum by metal plating, thereby providing the electrostatic and magnetic shields between the transducer elements as in the foregoing.

95 Although the transducer liners are fixed to both the upper and lower sides of the circular plate 10, and the transducer elements are sandwiched by the transducer liners as illustrated in Figure 5, it should be noted that only the lower transducer liners 12A 100 are fixed to the circular plate 10A and the transducer elements are mounted thereon.

Although a plurality of the circular plates are used in the foregoing embodiments of the invention, it should be noted that a plurality of rectangular plates 105 can be also used, and a plurality of the transducer elements are arranged on an imaginary straight line. As a result, a planar array of the transducer elements is obtained. It should be also noted that a plurality of fan-like plates can be also used, and a plurality of the 110 transducer elements are disposed on an imaginary arc. A semicylindrical array of the transducer elements is obtained.

While the invention has been described in detail and with reference to specific embodiments thereof, 115 it will be apparent to one skilled in the art that various changes and modifications can be made thereto without departing from the spirit and scope of the invention.

120 CLAIMS

1. A transducer device comprising:
 - (i) a plurality of rows of transducer elements, with said each row comprising a plurality of the transducer elements disposed on an imaginary line,
 - (ii) a plurality of plates, with said each plate supporting one of said rows of the transducer elements,
 - (iii) spacers for spacing the two adjacent plates of said plurality of plates at predetermined space

- intervals,
- (iv) acoustic insulation material maintained between said two adjacent rows of the transducer elements,
- 5 5 (v) sound passing material covering the front surfaces of said transducer elements arranged in rows and columns, and
- (vi) enclosing means for water-tightly enclosing said arranged transducer elements supported by
- 10 said plurality of the plates.
2. A transducer device as defined in claim 1 wherein said transducer element comprises a magnetostrictive ultrasonic transducer.
3. A transducer device as defined in claim 1
- 15 wherein said transducer element comprises an electrostrictive ultrasonic transducer.
4. A transducer device as defined in claim 1 wherein said plate is made of non-magnetic material.
- 20 5. A transducer device as defined in claim 1 wherein said acoustic insulation material is made of sponge.
6. A transducer device as defined in claim 1 wherein said sound passing material is made of
- 25 urethane rubber.
7. A transducer device as defined in claim 1 wherein said spacers are of the same length.
8. A transducer device comprising:
- (i) a plurality of rows of transducer elements, with
- 30 each said row comprising a plurality of transducer elements disposed on an imaginary circle at uniform angular space intervals in radially extending relation,
- (ii) a plurality of circular plates, with said each
- 35 circular plate supporting one of said rows of the transducer elements,
- (iii) spacers for spacing the two adjacent circular plates of said plurality of the circular plates at predetermined space intervals,
- 40 (iv) acoustic insulation material maintained between said two adjacent rows of the transducer elements,
- (v) sound passing material covering the front surfaces of said transducer elements arranged in
- 45 rows and columns, and
- (vi) enclosing means for water-tightly enclosing said arranged transducer elements supported by
- 50 said plurality of circular plates.
9. A transducer device as defined in claim 7
- 55 wherein said spacers are of the same length.
10. A transducer device comprising:
- (i) a plurality of rows of transducer elements, with said each row comprising a plurality of transducer elements disposed on an imaginary arc,
- 55 (ii) a plurality of fan-like plates, with said each plate supporting one of said rows of the transducer elements,
- (iii) spacers for spacing the two adjacent plates of said plurality of the plates at predetermined space
- 60 intervals,
- (iv) acoustic insulation material maintained between said two adjacent rows of the transducer elements,
- (v) sound passing material covering the front
- 65 surfaces of said transducer elements arranged in
- rows and columns, and
- (vi) enclosing means for water-tightly enclosing said arranged transducer elements supported by
- 70 said plurality of the plates.
11. A transducer device substantially as hereinbefore described with reference to and as illustrated in Figures 4 to 7 of the accompanying drawings.

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